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EFFECTS OF LOGGING ON GROWTH OF JUVENILE COHO SALMON

Paul M. Iwanaga, et al

Oregon State University

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Effects of Logging on Growth of Juvenile Coho Salmon

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EFFECTS OF LOGGING ON GROWTH OF JUVENILE COHO SALMON

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ABSTRACT

The objective of this research was to study the effects of increased water temperature characteristic of clearcut watersheds of Pacific coastal streams upon the growth rate of juvenile coho salmon. The natural temperature fluctuations of the stream were used in the study of growth of underyearling fish held in aquariums and fed at various consumption levels.

Juvenile coho experiencing the cooler temperatures of the control stream demonstrated generally better growth rates than did those that experienced the warmer temperatures of the clearcut stream. The reduced maintenance requirements in the control experiment indicated a reduced basal metabolic demand, which allowed for a greater portion of the food consumed to be utilized for growth. This was particularly true at low levels of consumption.

Growth rates of juvenile coho salmon in the wild state were found to be slightly higher in the clearcut stream as compared to the unlogged stream. This difference from the experimental results may have been due to a change in availability and abundance of food. There was a marked decrease in the cutthroat trout population in the clearcut stream, which may have reduced competition for the coho salmon. There was no apparent influence of infestation by "salmon poisoning" fluke on the condition of the juvenile coho in the clearcut stream.

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CONTENTS

Section		Page
I	Introduction	1
II	Materials and Methods	5
III	Results and Interpretation	11
IV	Acknowledgments	31
V	References	33

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FIGURES

		Page
1	Map of the study watersheds	3
2	Temperature pattern on the days of the annual maximum recorded on the clearcut and uncut control watersheds before (1965), during (1966), and after (1967-1969) logging	9
3	Relationship between growth rate and consumption rate of coho from the clearcut and control streams	12
4	Relationship between mean temperature and change in weight of coho at starvation and 2 and 4 percent rations in the control stream	13
5	Relationship between mean temperature and change in weight of coho at starvation and 4 and 8 percent rations in the clearcut stream	14
6	Relationship between diel temperature fluctuation and change in weight of coho at starvation and 2 and 4 percent rations in the control stream	15
7	Relationship between diel temperature fluctuation and change in weight of coho at starvation and 4 and 8 percent rations in the clearcut stream	16
8	Relationship of consumption rate and growth rate to mean temperature of coho on repletion rations in the control stream	18
9	Relationship of consumption rate and growth rate to mean temperature of coho on repletion rations in the clearcut stream	19
10	Relation between coefficient of condition and the number of cysts in juvenile coho salmon from three coastal streams	26
11	Change in mean length of juvenile coho from Needle Branch (clearcut) and Flynn Creek (control) before logging	27

FIGURES (continued)

		Page
12	Change in mean length of juvenile coho from Needle Branch (clearcut) and Flynn Creek (control) after logging	28

TABLES

No.		Page
1	Stream temperature (°C) experiences of the juvenile coho from the control and clearcut watersheds	10
2	Comparison of growth rate in paired experiments with similar mean temperatures and/or diel temperature fluctuations	22
3	Lengths, weights, and cyst infestation of juvenile coho salmon	25

SECTION I

INTRODUCTION

Lumbering is Oregon's major industry. Because of the extent of its operation, timber harvest can create serious problems for coho salmon populations utilizing headwater tributaries for spawning and rearing areas. Besides siltation and stream blockage by debris, clearcut logging can cause significant increases in water temperature during the summer, when streamflow is low. Loss of streamside cover allows direct sunlight to strike the water surface, causing more radiant energy to be absorbed (Brown, 1970). Temperatures as high as 30 C and diel fluctuations as much as 16 C have been recorded from small clearcut streams (Brown and Krygier, 1970). The effect of such temperature variations on fish must be better understood so steps can be taken to harvest the timber with the minimum amount of damage to the salmon populations.

The objective of this research was to study the effects of increased water temperature characteristic of clearcut watersheds upon the growth rate of juvenile coho salmon. To accomplish this, studies of food consumption and growth rate similar to those described by Warren and Davis (1967) were conducted during the critical summer period.

Temperature exerts a significant influence upon the life history of coho salmon. In addition to affecting food utilization and growth, stream temperatures also can retard or accelerate the hatching and emergence of fry, and, in extremes, cause mortality. Temperature can also influence juvenile coho populations by increasing or decreasing their food resource and by making conditions more or less favorable for competing species.

Many animals exhibit a particular range of temperature that is optimal for growth. Temperature affects metabolism such that increased cost of maintenance at higher temperature reduces the efficiency at which an animal utilizes a given amount of food consumed for growth (Warren and Davis, 1967). Optimum temperature for growth increases with ration size (Brett, Shelbourn, and Shoop, 1969). This optimum could be associated with the action of enzymes, which themselves demonstrate an optimum temperature for activity (Bell, Davidson, and Scarborough, 1968). There is also a seasonal variation in metabolism in some fishes, metabolism being usually higher during winter than summer (Bullock, 1955; Wells, 1935).

There has been little research on the effects of large natural fluctuations in diel temperature on the growth or survival of fish. Almost all work on temperature effects has been conducted at constant temperature or has involved sudden temperature shock. Mortalities

due to temperature extremes are a function of both temperature and exposure time (Brett, 1952). Exposures of fish to different temperatures above their lethal level, without intervals of sublethal temperature, were found to be cumulative in causing mortality (Fry, Hart, and Walker, 1946). Fry et al. (1946) did demonstrate that acclimation to higher temperature occurred if the fish were allowed periodic exposures to sublethal temperatures. Likewise, experiments with rabbits revealed that a few hours of cooling each day offset the lethal effects of high temperatures (Ogle and Mills, 1933). Although increased acclimation temperature resulted in increased upper temperature tolerances for the opossum shrimp, Neomysis awatschensis, it also resulted in decreased tolerances to rapid temperature changes, occurring within a 1-hour period (Hair, 1971).

Maximum temperatures of 30 C were recorded for short periods during the days of maximum diel temperature fluctuations in a small Oregon stream under intensive study following clearcut logging (Brown and Krygier, 1970). These high temperatures, above the 25 C upper lethal temperature for juvenile coho (Brett, 1952), may produce mortality, or cause fish to move to cooler portions of the stream. The cool night temperatures may have a buffering effect upon the high daytime temperatures by providing a recovery period and, thus, allow the coho to survive. The amplitude of the diel temperature fluctuation gradually increased from early spring to late summer, perhaps allowing the fish to acclimate to the rapidly changing diel temperatures as well as the high maximum temperatures. This research was designed to provide additional information on the fate of salmon in small tributaries such as those that exhibit such large daily temperature variations as a result of clearcut logging.

The research was carried out on tributaries of Drift Creek, which flows into the Alsea Bay near Waldport, Oregon. Work was concentrated on two streams, Deer Creek and Needle Branch, which drain watersheds of 304 hectares and 75 hectares, respectively (Figure 1). These watersheds are subjects of a 15-year study on the effects of logging practices on water quality and fish resources (Hall and Lantz, 1969). In 1966, after seven years of pre-logging study, the Needle Branch watershed was completely clearcut and burned. Deer Creek was partially clearcut. Three patches involving about 30 percent of the watershed were cut, and a strip of vegetation was left along the streambank. The streams have upstream - downstream fish traps and were provided with stations for measurements of such environmental parameters as temperature, streamflow, and sediment load.

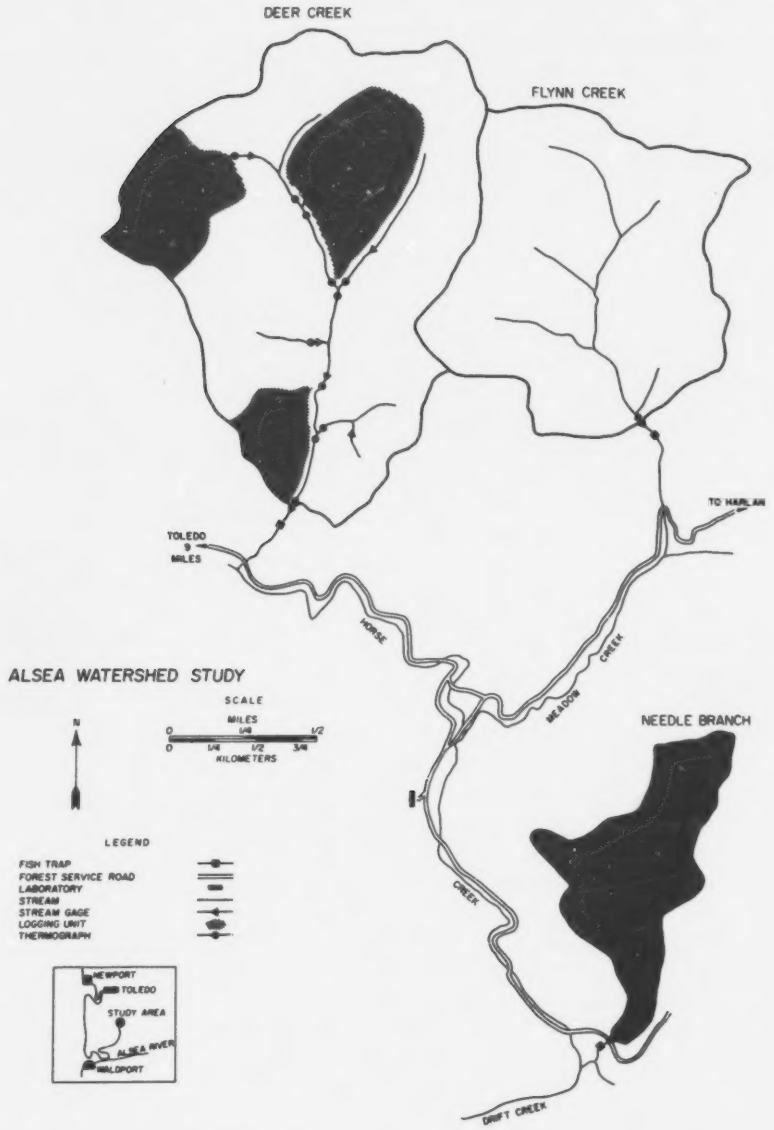

Figure 1. Map of the study watersheds.

SECTION II

MATERIALS AND METHODS

Wild underyearling coho salmon of uniform size (50 to 65 mm) were fed standardized rations during exposure to the high fluctuating temperatures of the clearcut stream. The resultant food consumption and growth rates were compared to those of fish fed at similar rates, but exposed to the cooler and more stable temperatures of the shaded stream. Water was taken directly from the two streams to utilize the natural temperature regime.

Fish were held in individual compartments in two types of aquariums. The first experiment made use of styrofoam cooler boxes that were divided with plexiglass into four compartments (19 x 19 x 20 cm deep). Four of these aquariums were used at each stream. Interchange of water occurred between compartments of each aquarium, but no interchange of food was allowed. The remaining experiments were carried out in plexiglass aquariums which were divided into eight compartments. Each compartment (15 x 25 x 20 cm deep) had its own water inlet and outflow, allowing no interchange of water or food. Two of these aquariums were used on each stream.

Water was piped from a pool above the fish trap and delivered to each compartment in the aquarium via a system of tygon tubing. The inlet water was passed through a cloth filter, and the aquarium tops were screened to keep natural food from reaching the fish. The temperature in one cell of each aquarium was recorded with a Partlow thermograph and was also periodically checked with an accurate hand thermometer.

The rations for the experiment consisted entirely of larvae of the common house fly (Musca domestica) hatched in gallon jars of artificial media. The larvae were separated from the media, placed in aluminum pans, and frozen in water.

Rations used were as follows: 1) starvation, 2) estimated maintenance, 3) twice the estimated maintenance, and 4) repletion. This design resulted in higher rations being fed to fish in the clearcut stream, based on an estimate of the increased maintenance ration that would be required as a result of the higher temperatures there. The fish in the clearcut stream were fed at 4 (maintenance) and 8 percent of body weight as compared to 2 (maintenance) and 4 percent in the control stream.

During the first three experiments, rations were fed according to percentage of initial body weight and were weighed out daily from the supply of frozen larvae. The procedure was changed for the last

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three experiments to reduce weighing error. The 2-week ration for each fish was weighed and divided into 14 approximately equal parts, frozen, and fed to the coho each day. This method also reduced some of the daily routine of weighing larvae.

Rations of coho fed to repletion were calculated by multiplying the number of larvae eaten by the average weight of the larvae. Groups of 25 to 30 larvae of uniform size were weighed to determine average weight and frozen in an aluminum pan. The pan was numbered and one pan of larvae used per day for each fish on a repletion ration.

For simplicity, the fish will be referred to in the discussion by their ration size, estimated on the basis of initial wet weight (i.e., 2, 4, and 8 percent). However, in the figures, feeding levels are expressed in terms of the average dry weight equivalents. Because of growth of the fish during the experiment and the fact that the food had a lower percent dry weight than did the fish, actual feeding rates that resulted were approximately 15, 30, and 55 mg/g/day, respectively.

Juvenile coho were taken from the study streams and held in the aquariums for 1 week before each experiment was begun. Sixteen fish out of 28 that began the acclimation period were used at each stream. The compartmentalized aquariums were divided in half to temporarily hold the 28 fish for acclimation. The coho were weighed, measured, and fed a ration that they would receive during the experiment. The fish scheduled to be on starvation during the experiment were fed the maintenance ration. For the last 3 days of the acclimation period, all fish were observed closely. Those chosen for the experiment were the ones that fed readily and ate all their ration.

The fish were first anesthetized in tricaine methane sulfonate (MS 222) and measured to the nearest 0.5 mm. They were then damp dried and weighed to the nearest 0.001 gm. At the end of the experiment dry weights were measured after the coho had been in a drying oven (65 - 70 C) for 3 to 5 days and in a dessicator for another 2 days.

The parameters of consumption rate, growth rate, and gross efficiency were those used by Warren and Davis (1967) and were based upon dry weight. The dry weight of food consumed was determined by multiplying the consumption by the average percentage dry weight of several samples of larvae. The initial dry weight of the fish was estimated by multiplying the initial wet weight times the percentage dry weight at the final weighing.

A small sample of fish was sacrificed at the beginning of several experiments. Based on a comparison of the percentage dry weight of these fish and those measured at the end of the experiments, it was assumed that there was no change in percentage dry weight of the

fed fish during the feeding experiments. The initial dry weights for the starved coho were determined by using the average percentage dry weight of the fish on maintenance rations, since it is known that starvation affects this parameter. The average of the initial and final dry weight was then used in the following computations:

$$\text{Consumption rate} = \frac{\text{total consumption (mg)/average weight (g)}}{\text{14 days (length of experiment)}}$$

$$\text{Growth rate} = \frac{\text{growth (mg)/average weight (g)}}{\text{14 days}}$$

$$\text{Gross efficiency} = \frac{\text{total growth (mg)}}{\text{total consumption (mg)}}$$

The coefficient of condition (K) was used to express the well being (relative robustness) of the fish in numerical terms. Changes in K reflect changes in the relationship between length (L) and weight (W):

$$K = \frac{W \times 10^5}{L^3}$$

The integral mean temperature (referred to as mean temperature) was calculated for each day and was derived as follows:

$$\text{Integral mean temperature} = \frac{1}{T} \int_0^T y(t)\, dt$$

T = 24 hours

t = 2 hours

y = temperature

Temperatures were taken from thermograph charts at 2-hour intervals for each 24-hour period. The integral mean temperatures were averaged for each experiment. The arithmetic mean of daily maxima and minima was used to determine the mean diel fluctuation.

The decision to use naturally fluctuating temperatures in the study streams caused difficulties in interpretation of the results because of unusual weather conditions and rapid regrowth of vegetation on the clearcut stream. The summer of 1968 (experiments 1, 2, and 3) proved to be unusually cloudy and wet, particularly after August 12. There was an overall trend of decreasing instead of increasing water temperatures from July through September. The wet conditions also increased the turbidity of the water for much of the second and third experiments. Normal dry weather conditions prevailed during the summer of 1969 (experiments 4, 5, and 6). Stream temperatures followed the normal increasing trend through August followed by a decreasing trend in September. Turbidity was not much of a problem, except during an occasional summer rain.

Needle Branch underwent a progressive change in streamside vegetation from 1967 to 1969. The vegetation was relatively low during the summer of 1968, allowing direct exposure of the stream to sunlight for most of its length. The following summer the alder (Alnus rubra) grew extensively, resulting in almost complete shading of the entire stream. This shading considerably moderated the high temperatures that had been experienced in the previous 2 years (Figure 2). To partially compensate for this, vegetation was cleared along a short stretch of stream immediately above the fish trap. This allowed more direct sunlight to strike the stream and maintain the higher temperatures more nearly representative of the years immediately following logging, although they were still substantially lower than those during 1967.

The undisturbed control stream (Flynn Creek) was not regularly accessible during the summers of 1968 and 1969 because of road construction. Thus the patch-cut stream (Deer Creek) was used as a control in 1968. Although there was not a significant increase in the temperature of the main stream (Brown and Krygier, 1970), exposure of the stream water to solar radiation in the pond immediately above the fish trap resulted in a significantly higher temperature fluctuation than that of Flynn Creek. In 1969, the control was moved to the laboratory, where a small shaded stream was used as the water supply, resulting in water temperatures more closely representative of those in the undisturbed control (Table 1).

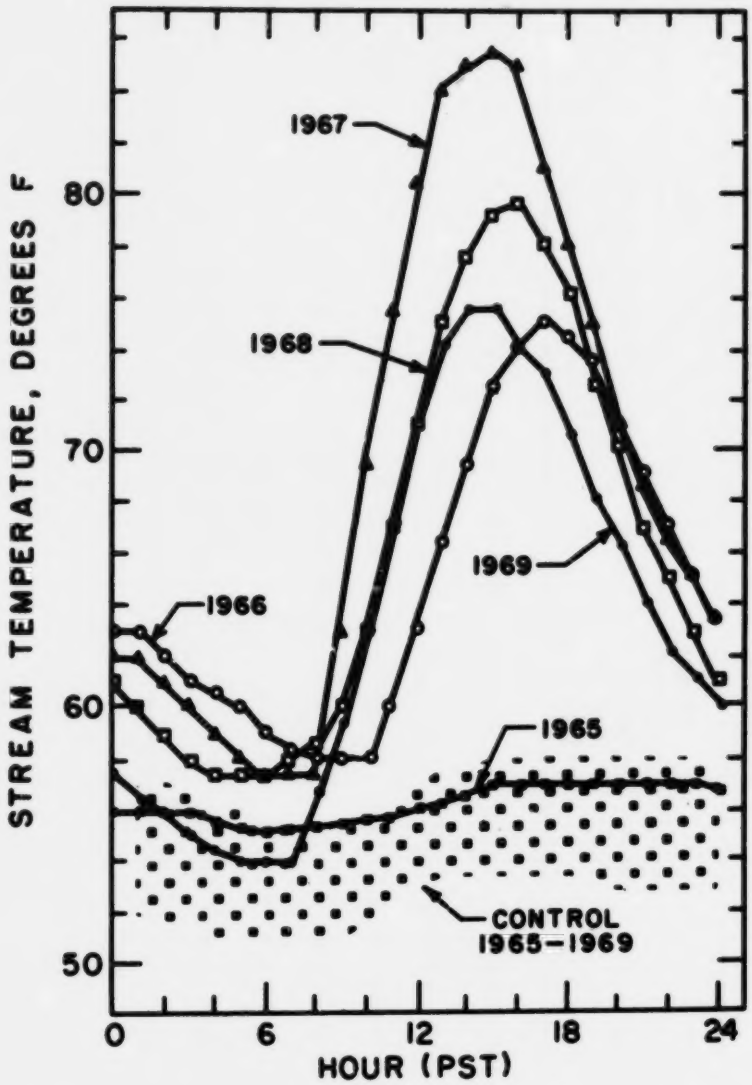

Figure 2. Temperature pattern on the days of the annual maximum recorded on the clearcut and uncut control watersheds before (1965), during (1966), and after (1967-1969) logging. (From Brown and Krygier, 1970)

TABLE 1. Stream temperature (°C) experiences of the juvenile coho from the control and clearcut watersheds.

Exp. No.	Date	CONTROL			CLEARCUT		
		Mean Temp.	Mean Diel Fluct.	Range	Mean Temp.	Mean Diel Fluct.	Range
1	19 July-1 Aug. 1968	14.5	4.2	9.4-17.5	17.3	6.8	11.1-22.5
2	16 Aug.-29 Aug. 1968	13.4	1.4	10.6-14.4	14.6	2.6	11.6-17.5
3	11 Sept.-24 Sept. 1968	11.9	1.8	9.7 14.4	13.6	3.2	10.6-18.4
4	11 July-24 July 1969	10.8	2.6	8.4-14.4	15.0	7.6	9.7-22.2
5	8 Aug.-21 Aug. 1969	11.4	2.3	8.4-13.9	15.4	7.6	10.0-23.9
6	5 Sept.-18 Sept. 1969	10.8	1.5	8.4-12.4	14.8	9.0	7.8-25.6

SECTION III

RESULTS AND INTERPRETATION

Growth Rates of Juvenile Coho Salmon From Shaded and Unshaded Streams

Juvenile coho salmon experiencing the cooler temperatures of the control stream were generally found to grow more rapidly than did those that were held in the warmer temperatures of the clearcut stream (Figure 3). The reduced maintenance requirements of control fish probably resulted from a reduced basal metabolic demand allowing a greater portion of the food consumed to be utilized for growth. This was particularly true at low levels of consumption.

In several experiments, coho at the higher food consumption levels in the clearcut stream had growth rates approaching or surpassing those of the control stream. The clearcut stream may have provided the necessary increased water temperature to complement the higher rations. An increased optimum temperature for growth with an increased ration is consistent with results reported by Brett et al. (1969). However, these results at higher food consumption levels may not apply to many situations in nature, in light of information regarding the low feeding levels of wild fish, based on caloric values as an index to level of nutrition (Warren and Davis, 1967). Caloric values of wild coho under natural feeding conditions were similar to those of experimental juvenile coho on low feeding rations (L. Everson, unpublished data, Department of Fisheries and Wildlife, Oregon State University). Such evidence for a low feeding rate in nature would suggest an overall detrimental effect of increased temperatures upon growth, providing that food availability remained unchanged.

Effects of Temperature Levels Within the Streams

The design of the experiment was not well suited for analysis of the effect on growth rate of the relatively small differences in mean temperature encountered within a stream. In addition, daily temperature fluctuations probably had at least as significant an effect on growth rate as did the small differences in mean temperature among the experiments (Figures 4, 5, 6, and 7). However, further analysis of the data may give some additional information that may help us to understand the effects of increased temperature on growth.

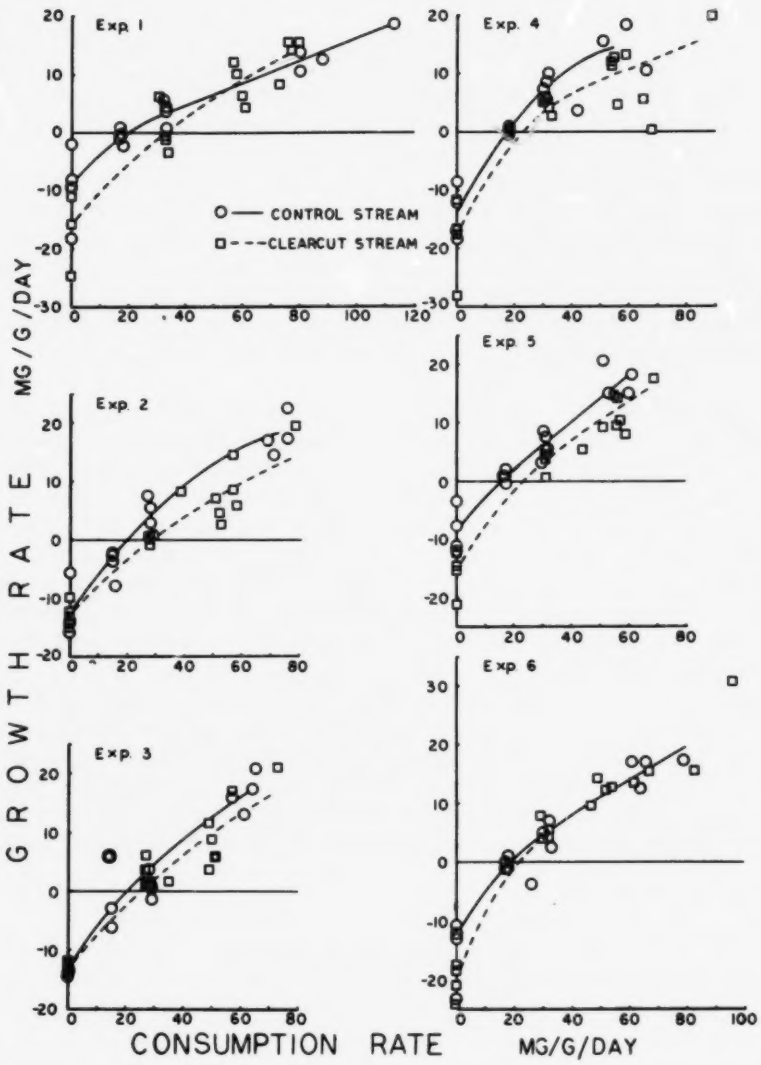

Figure 3. Relationship between growth rate and consumption rate of coho from the clearcut and control streams. Curves fitted by inspection.

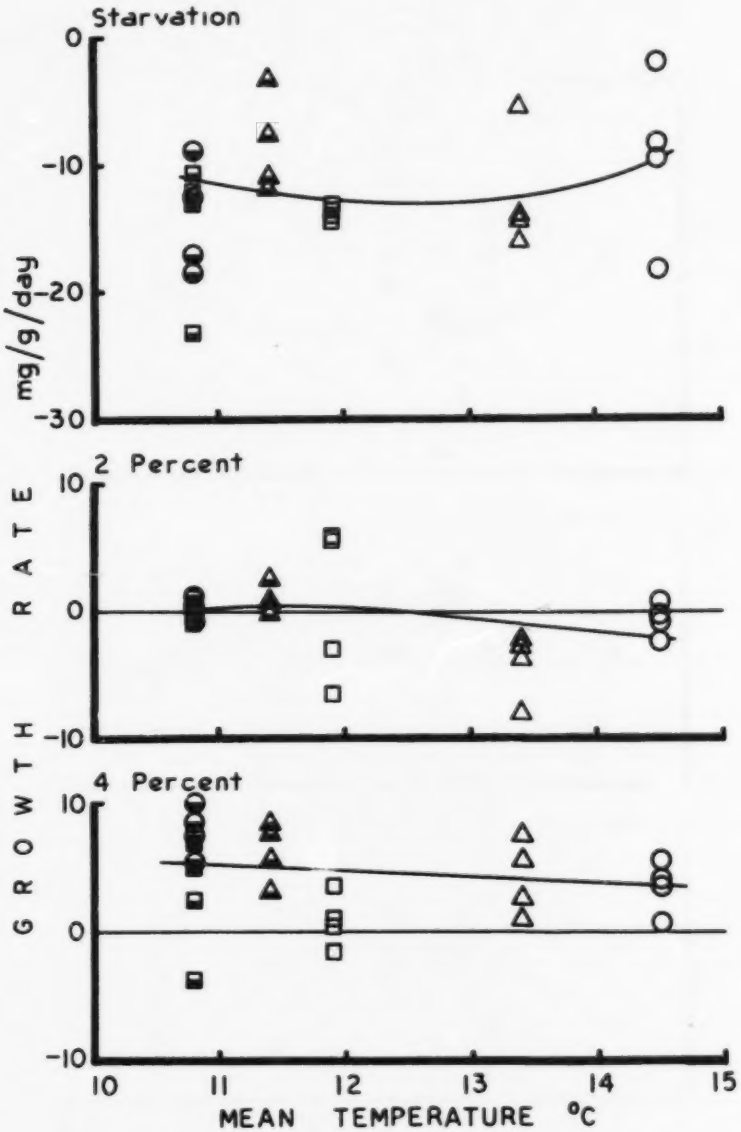

Figure 4. Relationship between mean temperature and change in weight of coho at starvation and 2 and 4 percent rations in the control stream. Curves fitted by inspection. Symbol and mean temperature fluctuation (in parenthesis) for each experiment:

- ○ Exp. 1 (4.2 C)
- △ Exp. 2 (1.4 C)
- □ Exp. 3 (1.8 C)
- ◒ Exp. 4 (2.6 C)
- ▲ Exp. 5 (2.3 C)
- ◙ Exp. 6 (1.5 C)

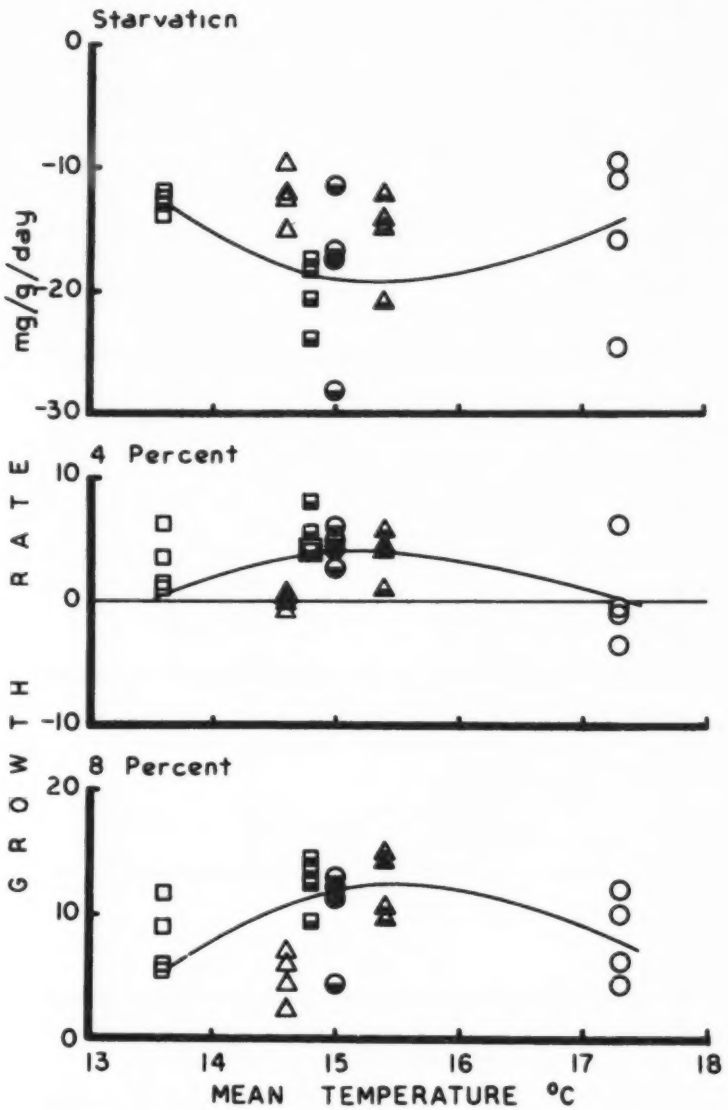

Figure 5. Relationship between mean temperature and change in weight of coho at starvation and 4 and 8 percent rations in the clearcut stream. Curves fitted by inspection. Symbols and mean temperature fluctuation (in parenthesis) for each experiment:

○	Exp. 1 (6.8 C)	◒	Exp. 4 (7.6 C)
△	Exp. 2 (2.6 C)	▲	Exp. 5 (7.6 C)
□	Exp. 3 (3.2 C)	◘	Exp. 6 (9.0 C)

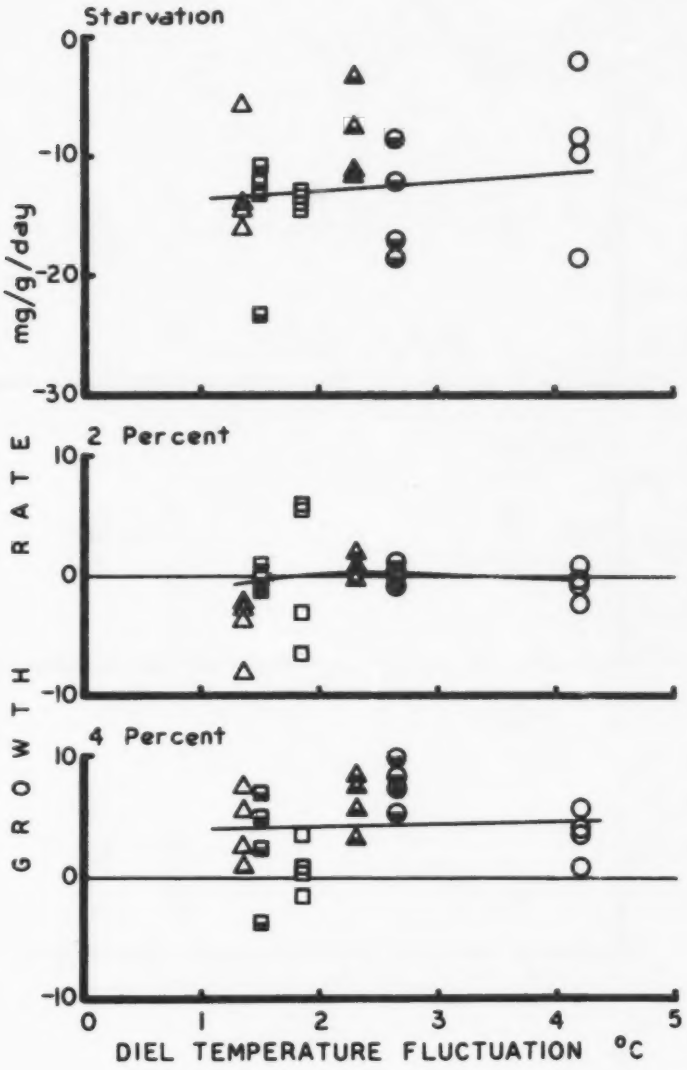

Figure 6. Relationship between diel temperature fluctuation and change in weight of coho at starvation and 2 and 4 percent rations in the control stream. Curves fitted by inspection. Symbols and mean temperatures (in parenthesis) for each experiment:

- ○ Exp. 1 (14.5 C)
- △ Exp. 2 (13.4 C)
- □ Exp. 3 (11.9 C)
- ◒ Exp. 4 (10.8 C)
- ▲ Exp. 5 (11.4 C)
- ◙ Exp. 6 (10.8 C)

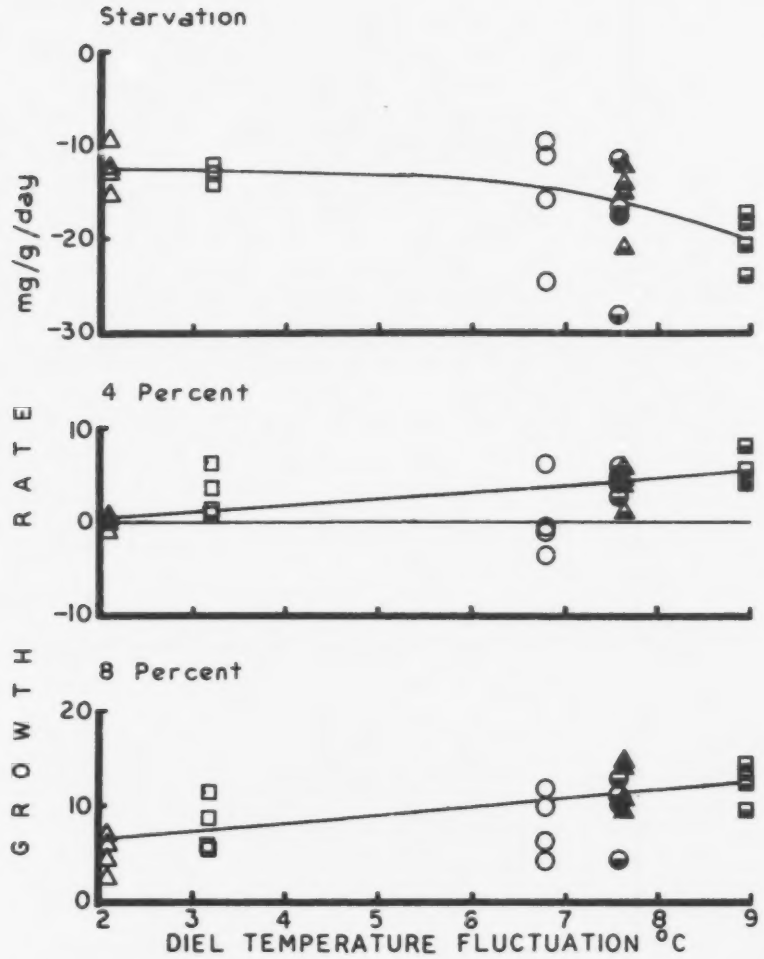

Figure 7. Relationship between diel temperature fluctuation and change in weight of coho at starvation and 4 and 8 percent rations in the clearcut stream. Curves fitted by inspection. Symbols and mean temperatures (in parenthesis) for each experiment:

- ○ Exp. 1 (17.3 C)
- △ Exp. 2 (14.6 C)
- □ Exp. 3 (13.6 C)
- ◒ Exp. 4 (15.0 C)
- ▲ Exp. 5 (15.4 C)
- ◘ Exp. 6 (14.8 C)

The variations in mean temperature experienced in each successive experiment within a given stream did not consistently influence growth rates (Figures 4 and 5). In the control experiment, with a mean temperature range from 10.8 to 14.5 C, there was considerable variability, but no indication of a relationship between growth rate and temperature, either at the 2 or the 4 percent feeding levels (Figure 4). In the clearcut stream, with a range in mean temperature from 13.6 to 17.3 C, there was some indication of an optimum temperature range for growth (Figure 5). The optimum range was approximately the same for fish on 4 and 8 percent rations. Since these fish were fed a fixed ration, any increase in growth rate within a range of temperature must have been due to a more efficient utilization of energy consumed.

The relationship between growth and diel fluctuation was different between fish from the control and the clearcut streams. The growth of the coho fry from the control stream remained relatively unchanged with increasing temperature fluctuations (Figure 6).

The higher temperature fluctuations in the clearcut stream, however, were associated with a slightly increased growth rate (Figure 7). At the higher fluctuations (6 - 9C) the starved fish lost an increasing amount of weight. The higher diel fluctuations may have increased the efficiency of food utilization in a manner similar to that of an optimum temperature range for growth. We could speculate that further increases in temperature fluctuations would ultimately result in a decreased growth rate. The increased weight loss of the starved fish may be attributed to an increased drain on body reserves to meet the increased metabolic demand.

The fish on repletion rations ate different amounts, thus evaluating growth rates directly without considering consumption levels would be meaningless. Increasing mean temperatures (10.8 to 14.5 C) in the control stream resulted in a relatively unchanged growth rate. An increased consumption rate together with a relatively unchanged growth rate suggests that efficiency of energy utilization decreases with increasing mean temperatures (Figure 8).

Increasing mean temperatures (13.6 to 17.3 C) in the clearcut stream also resulted in a relatively unchanged growth rate (Figure 9). The rate of food consumption increased with increased mean temperature, also indicating a decrease in food conversion efficiency.

The influence of temperature on growth rate was somewhat different in the two streams, since there was a greater influence of daily temperature variations in the clearcut stream than in the control stream. The reasons for this difference are not immediately apparent, since the difference in temperature range (3.7 C) was identical in both streams (10.8 to 14.5 C vs.13.6 to 17.3 C). Aside from the obviously higher range in the clearcut stream, the average diel

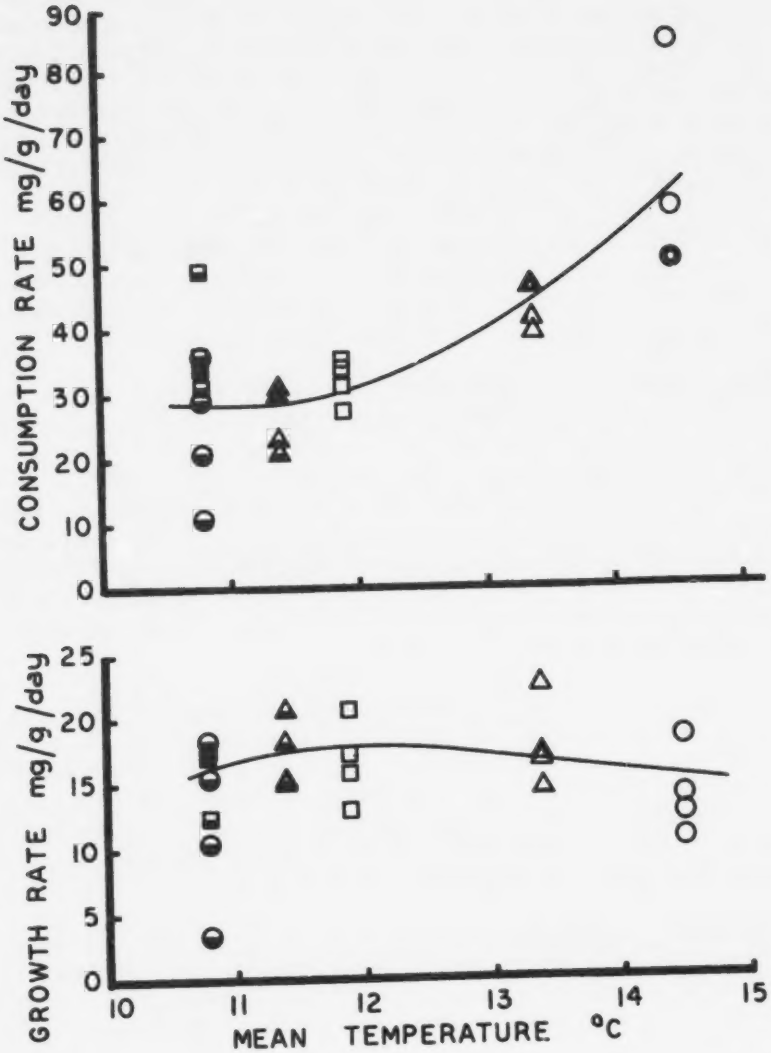

Figure 8. Relationship of consumption rate and growth rate to mean temperature of coho on repletion rations in the control stream. Curves fitted by inspection. See Figure 3 for description of symbols.

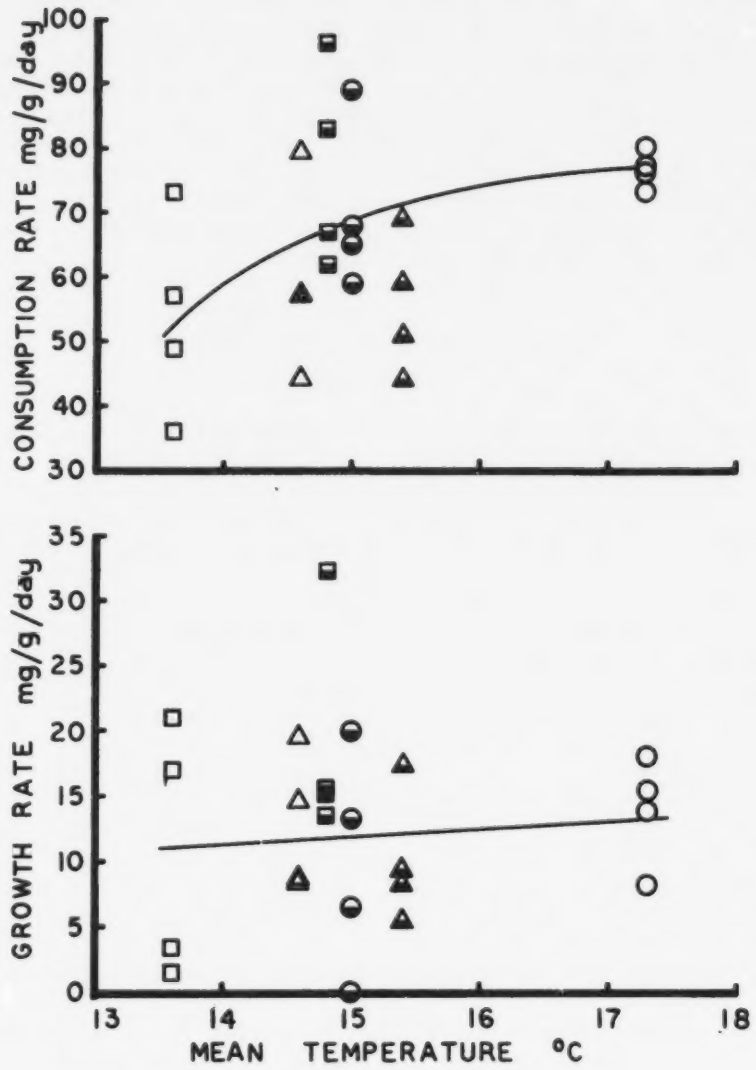

Figure 9. Relationship of consumption rate and growth rate to mean temperature of coho on repletion rations in the clearcut stream. Curves fitted by inspection. See Figure 5 for description of symbols.

fluctuation was significantly greater there. The possible implications of this difference are considered in a later section.

The possibility of inherent changes in growth rates through the summer months had been considered as a source of some of the unexplained variation. Figures 4 and 5 illustrate the lack of any detectable seasonal pattern in growth rate in either stream. Brown (1946) found that the growth rate of 2-year-old brown trout kept at constant temperatures decreased to a minimum during October and November, increased to a maximum in February, then decreased gradually until August, at which time it fell rapidly. Other experiments with constant temperatures have given evidence for a decreasing or lower growth rate through the summer (Bullock, 1955; Wells, 1935). In our case, however, temperature variation may have masked any seasonal change in growth rate.

Fish Under Starvation

Increasing mean temperatures and diel temperature fluctuations appear to have affected the starved fish from the control and clearcut streams differently. The relatively low diel temperature fluctuations at low mean temperatures in the control stream had little effect upon the weight loss of the coho (Figures 4 and 6).

In the clearcut stream, however, with greater temperature fluctuation and higher temperatures, there was a definite relationship between temperature and weight loss (Figures 5 and 7). The greatest loss in body weight occurred between 15.0 and 16.0 C (Figure 5), within the temperature range of optimum growth for the 4 and 8 percent ration level. The same pattern prevailed for increasing temperature fluctuation (Figure 7). In a feeding experiment with brown trout, the greatest weight loss also occurred at a temperature within the temperature range for optimum growth (Pentelow, 1939). The optimum temperature for growth of the trout was from 10.0 to 15.6 C and the greatest weight loss occurred from 12.8 to 15.6 C. This increase in loss of body weight most probably occurred in the temperature range where the metabolic processes of the fish were most active, and they therefore utilized the greatest amounts of their energy stores.

The validity of including starved fish on growth rate curves may be questioned, since growth implies the buildup of body tissues. Starvation results in the breakdown of tissues to produce the energy required to maintain body activities. Continued starvation creates a metabolic imbalance resulting in a decrease in the total organic content and increased percentages of water and ash in the tissues (Wilkins, 1967). It has also been demonstrated that at higher temperatures the same physiological activity (increased metabolic activity in a particular temperature range) resulted in increased growth rate of fed fish vs. increased weight loss of starved fish.

Separating the Effects of Increasing Mean Temperature and Diel Fluctuation

The design of this experiment resulted in a comparison of growth rates from two streams that differed in both mean temperature and diel temperature range. Growth rates could have been affected by either factor and it is difficult to separate their effects. From a management point of view it may not be significant which effect was more important, but further analysis was undertaken in an attempt to learn more about the mechanisms involved in the change in growth rate.

Knowledge of the effects of temperature fluctuation on growth of fish is lacking. However, entomologists have done much work on the influence of temperature change upon the development of insects. Increasing diel temperature fluctuation at lower than optimum mean temperature resulted in faster development of fruit fly eggs than at the equivalent constant mean temperature (Messenger and Flitters, 1959). Faster development has been attributed to an increased metabolic rate during periods of high temperature exposure (Cook, 1927). However, diel temperature fluctuations around the optimum constant temperature caused no improvement in developmental rate, and fluctuations above the optimum constant temperature resulted in a decrease in development rate as well as other adverse effects.

In an attempt to separate out the effects of temperature fluctuation, the growth rates and temperature experience of specific groups of fish were compared. Control stream experiments 2 through 6 and clearcut stream experiments 4, 5, and 6 were included in the comparison. These groups were chosen for comparison because the mean temperature or diel temperature fluctuations for these fish showed no more than an arbitrary 0.5 C difference. In order to facilitate the comparison, growth rates differing by 1 mg/g/day or less were considered equal.

The following rationale for evaluating the effects of mean temperature and diel temperature fluctuations on growth rate was used. Experiments in which the mean temperatures were similar were compared to estimate the effects of temperature fluctuation on growth rate while those in which temperature fluctuations were the same were compared to estimate the effects of mean temperature on growth rate.

The results of these comparisons, unfortunately, were inconclusive (Table 2). In this analysis, mean temperature appeared to be the dominant influence twice as often as did diel temperature fluctuation. There were four comparisons where the temperature regimes were the same, both for mean temperature and the mean fluctuation. Growth rates in two experiments were the same and in the other two they

TABLE 2. Comparison of growth rate in paired experiments with similar mean temperatures and/or diel temperature fluctuations

Food Level	Exps. Compared A	Exps. Compared B	Growth mg/g/day A	Growth mg/g/day B	Mean Temp.° C A	Mean Temp.° C B	Diel Fluct.° C A	Diel Fluct.° C B	Influential temperature parameter	Remarks
					CONTROL					
2%	3	5	0.4	0.8	11.9	11.4	1.8	2.3	neither	
	4	6	0.2	-0.3	10.8	10.8	2.6	1.5	mean temp.	Greater fluctuation did not influence growth rate.
	2	3	-4.2	0.4	13.4	11.9	1.4	1.8	mean temp.	Higher mean temp. resulted in reduced growth rate.
	2	6	-4.2	-0.3	13.4	10.8	1.4	1.5	mean temp.	Higher mean temp. resulted in reduced growth rate.
	3	6	0.4	-0.3	11.9	10.8	1.8	1.5	mean temp.	Higher mean temp. resulted in increased growth rate.
4%	3	5	0.8	6.2	11.9	11.4	1.8	2.3	neither	
	4	6	7.8	2.6	10.8	10.8	2.6	1.5	diel fluct.	Higher diel fluct. resulted in higher growth rates.
	2	3	4.0	0.8	13.4	11.9	1.4	1.8	mean temp.	Higher mean temp. resulted in increased growth rate.
	2	6	4.0	2.6	13.4	10.8	1.4	1.5	mean temp.	Higher mean temp. resulted in increased growth rate.
	3	6	0.8	2.6	11.9	10.8	1.8	1.5	mean temp.	Higher mean temp. resulted in decreased growth rate.
					CLEARCUT					
4%	4	5	4.4	3.6	15.0	15.4	7.6	7.6	neither	
	4	6	4.4	5.3	15.0	14.8	7.6	9.0	diel fluct.	Higher diel fluct. resulted in increased growth rate.
8%	4	5	10.1	12.5	15.0	15.4	7.6	7.6	neither	
	4	6	10.1	12.4	15.0	14.8	7.6	9.0	diel fluct.	Higher diel fluct. resulted in increased growth rate.

were different. These results suggest the possibility that factors other than temperature and food consumption were affecting growth rate, as the scatter of points in the previous figures would suggest.

On the few occasions when diel temperature fluctuation appeared to be the dominant influence, increased growth rates were associated with increased temperature fluctuation. The lack of a definite result in this analysis suggests that both mean temperature and diel temperature fluctuation influenced the growth of juvenile salmon under conditions of this experiment.

It should be emphasized that in a system of fluctuating temperatures fish do not actually experience the mean temperature as such. A mean temperature is employed as a convenient means of expressing the dynamic temperature changes that occur in natural streams. It would be more realistic if the temperature experiences could be expressed with consideration for the continuous and dynamic nature of natural stream temperatures. A more complete analysis of the problem should be conducted under controlled laboratory conditions where fish could be subjected to mean temperatures at several levels combined with varying levels of diel fluctuation from 0 to 20 C.

Influence of Infestation by Nanophyetus salmincola

Another possible reason for unexplained variation in the experimental results was suspected to be a variable rate of infestation by the "salmon poisoning" fluke Nanophyetus salmincola. A heavy infestation of the fluke is known to affect the growth of juvenile coho salmon. Since the shedding rate of the cercariae from the snail host is known to be increased by increasing water temperature (Millemann and Knapp, 1970), it was hypothesized that the incidence of this fluke in juvenile salmon might increase significantly in the clearcut stream. With the assistance of Mr. Tom Robinson, an undergraduate in the Department of Fisheries and Wildlife, a survey of the problem was conducted.

There was no information available on the pre-logging abundance of the fluke in the streams, so all that was possible was a comparison of post-logging infestation in the three streams, clearcut, patch-cut, and control. A sample of 10 fish was taken from each stream during August and September of 1969 and processed according to methods described by Gebhardt et al. (1966).

From the evidence available, it appears that the hypothesis of increased infestation in the warmer clearcut stream was false. Fish from both the clearcut and patch-cut streams had a relatively low incidence of cysts as compared to those in the unlogged stream

(Table 3). There was no apparent relationship between the number of cysts and the condition of the coho fry (Figure 10). Logging may have created an environment that was unsuitable for a stage in the life cycle of N. salmincola, thereby reducing its effectiveness as a parasite on coho salmon.

Growth of Wild Coho From A Clearcut and Undisturbed Watershed

To evaluate the results of the experiment, it was desirable to compare the growth of coho in their natural environment to the growth of fish in the experiment. The mean lengths of juvenile coho sampled periodically from clearcut and undisturbed watersheds during pre-logging and post-logging years were compared. Flynn Creek was used as the control. Carline (1968) concluded that the technique was valid in that the growth rate of wild fish was comparable to those of aquarium-held fish that received the same amount of food as the wild fish.

Growth rates of fry prior to logging were compared during the same seasonal interval as the experiments (July through September). There was considerable variation among years, but no clear superiority of one stream over the other (Figure 11).

There was some evidence of better growth of fry in the clearcut stream during and shortly after logging, although the evidence was conflicting (Figure 12). Despite a high growth rate after emergence, the fry in the clearcut stream decreased in average length from July to September in 1967, the year of maximum temperature. Several hundred feet of stream were devoid of fish in the area where temperature was highest (D. Trethewey, unpublished data, Department of Fisheries and Wildlife, Oregon State University). Despite the finding by Dean and Coutant (1968) that size of juvenile fall chinook salmon did not influence their susceptibility to high lethal temperature, our results suggest that some differential mortality may have occurred. The possibility of sampling error cannot be discounted, however, as the sample in September was considerably larger than that in July (314 vs. 118).

The coefficient of condition provided an additional index to the well being of the coho fry in a clearcut watershed. During the hot summer of 1967 the fry grew rapidly in early summer, but showed a drop in condition in late summer. This loss of weight indicated extreme physical stress and the lack of food to maintain the initial nutritional level of the fry. The extreme temperatures characteristic of the summer of 1967 proved to be unfavorable for coho fry (D. Trethewey, unpublished data).

TABLE 3. Lengths, weights, and cyst infestation of juvenile coho salmon.

Date Sampled	Length (mm)	Weight (g)	Number of Cysts
	DEER CREEK		
9/5/69	61.0	2.38	34
	70.0	4.23	105
9/15/69	66.0	2.97	59
	71.0	3.94	167
	60.5	2.31	291
	68.5	3.27	178
	63.0	2.49	84
	63.0	2.51	31
	60.5	2.27	101
	58.5	2.09	68
	FLYNN CREEK		
8/26/69	59.0	2.18	414
	74.0	4.45	646
	57.0	1.87	440
9/9/69	63.0	2.67	1080
	71.0	3.52	346
	67.5	3.45	392
	68.5	3.59	639
	64.0	2.71	644
	68.0	3.21	921
	67.0	3.34	496
	NEEDLE BRANCH		
8/29/69	63.0	2.63	827
	61.5	2.45	176
9/2/69	71.5	3.77	72
	67.0	3.10	703
9/3/69	66.0	3.11	68
	68.0	3.34	84
	57.5	2.00	94
9/12/69	67.0	3.17	75
	67.5	3.49	112
	67.0	3.21	81

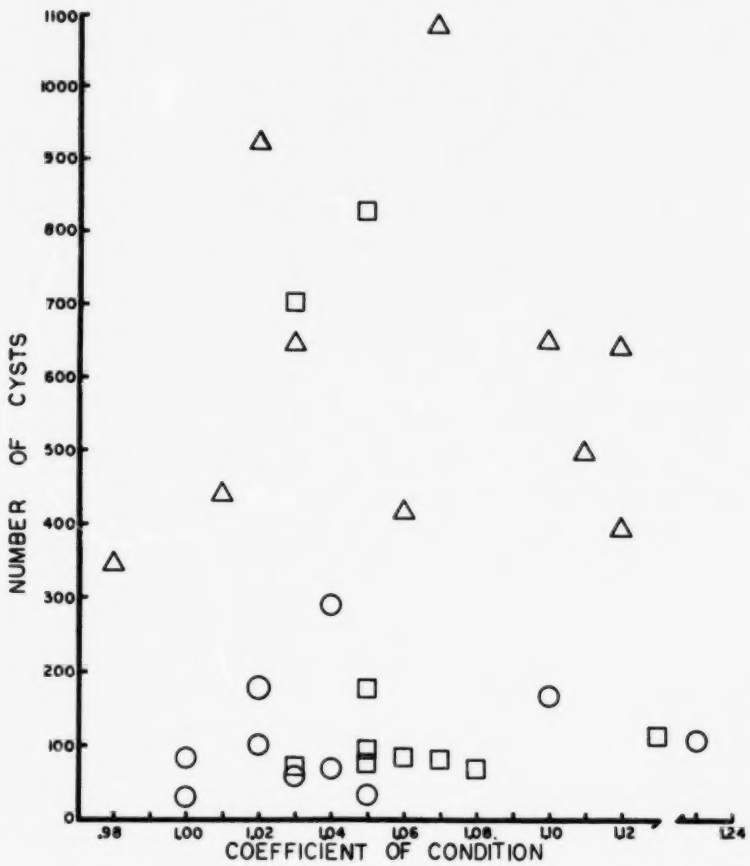

Figure 10. Relation between coefficient of condition and the number of cysts in juvenile coho salmon from three coastal streams.

△ Flynn Creek (Unlogged watershed)
○ Deer Creek (Patchcut watershed)
□ Needle Branch (Clearcut watershed)

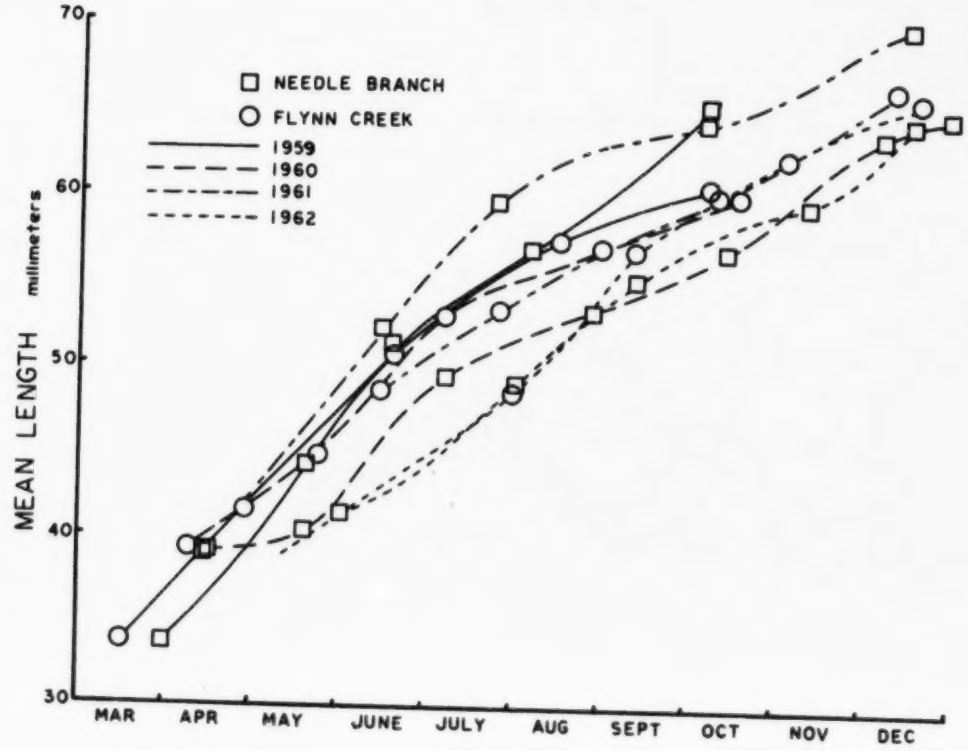

Figure 11. Change in mean length of juvenile coho from Needle Branch (clearcut) and Flynn Creek (control) before logging. Data from Chapman (1965).

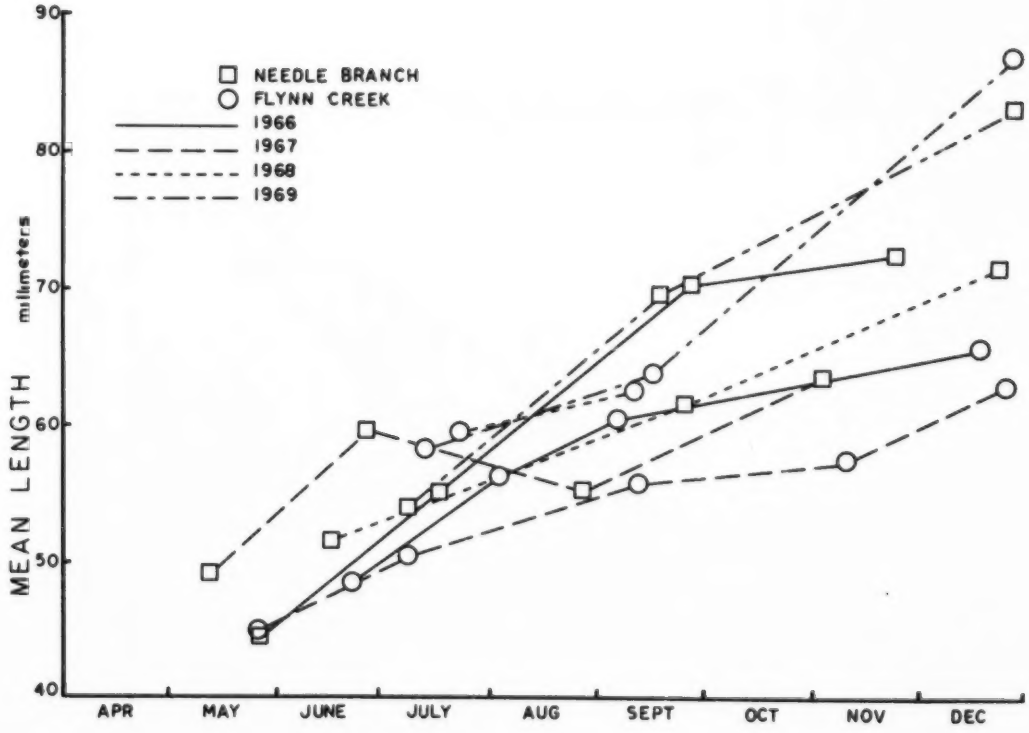

Figure 12. Change in mean length of juvenile coho from Needle Branch (clearcut) and Flynn Creek (control) after logging.

The difference in growth rates between the clearcut and control stream prior to logging was likely due to natural variations in environmental conditions. Those instances of higher growth rates in the clearcut stream after logging could be attributed to a number of interacting factors. One possible influence could have been an increased food production to offset the increase in metabolism the fish would have experienced under higher temperature, but there was no information on changes in food production following logging. The fact that most of the data available for growth comparisons relate to growth in length must be kept in mind. In the few cases where comparisons are available on a weight basis, the evidence for improved growth following logging is less clear.

Clearcutting resulted in less favorable conditions for cutthroat trout, bringing about a greater than 50 percent reduction in their numbers (Hall and Lantz, 1969). Cutthroat trout are known to interact with juvenile coho salmon, the presence of one species affecting the growth and survival of the other (McIntyre, 1970). Thus the reduced trout population may account in part for the apparent success of the coho population in the face of a severely altered environment.

Another factor that should be considered in evaluating the results is the possibility that the ration fed to the aquarium fish (fly larvae) was not an adequate diet nutritionally. The adequacy of the diet could have been different at different temperatures, possibly leading to poorer growth of aquarium fish at high temperatures. Further work should be done on this question.

The constant level of rations in the experiment makes somewhat difficult the comparison with a natural stream situation, where there are most likely periodic fluctuations in food availability. Slight increases in water temperatures have caused caddis flies to emerge as much as 2 weeks earlier than normal (Coutant, 1968). The higher temperatures of the clearcut stream might have altered the pattern of insect emergence and thus, subsequently reduced insect availability.

An analysis of the effects of increased temperature on fish populations should clearly focus on a broader spectrum than simply the metabolic changes that occur in the fish. The original design of this study included an analysis of food habits of fish from the control and clearcut streams. However, a delay in funding prevented accomplishment of that work, which would have provided additional insight into the changes occurring following logging.

It is evident that an evaluation of the effect of clearcut logging on the fisheries resource must consider many factors. The present research concerned itself mainly with growth of coho fry and indicated a reduced growth rate when food consumption levels were

unchanged. There was some evidence of slightly increased growth rates in the natural stream situation, due possibly to increased production and availability of food. The apparent increase in food may have been due to reduced competition from cutthroat trout. The recovery capabilities of a watershed must also be considered, since temperatures extreme as those of the summer of 1967 were adverse for the coho. Many watersheds would not recover as rapidly as did Needle Branch. In keeping with the total outlook, the significant reduction of cutthroat trout must also receive consideration as an important factor in judging the effects of clearcut logging on the fisheries resource. Evaluation of other impacts of logging in this stream system are discussed by Hall and Lantz (1969).

SECTION IV

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SECTION V

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